Top pair production distributions at the Tevatron

—includes Afb, differential cross sections —
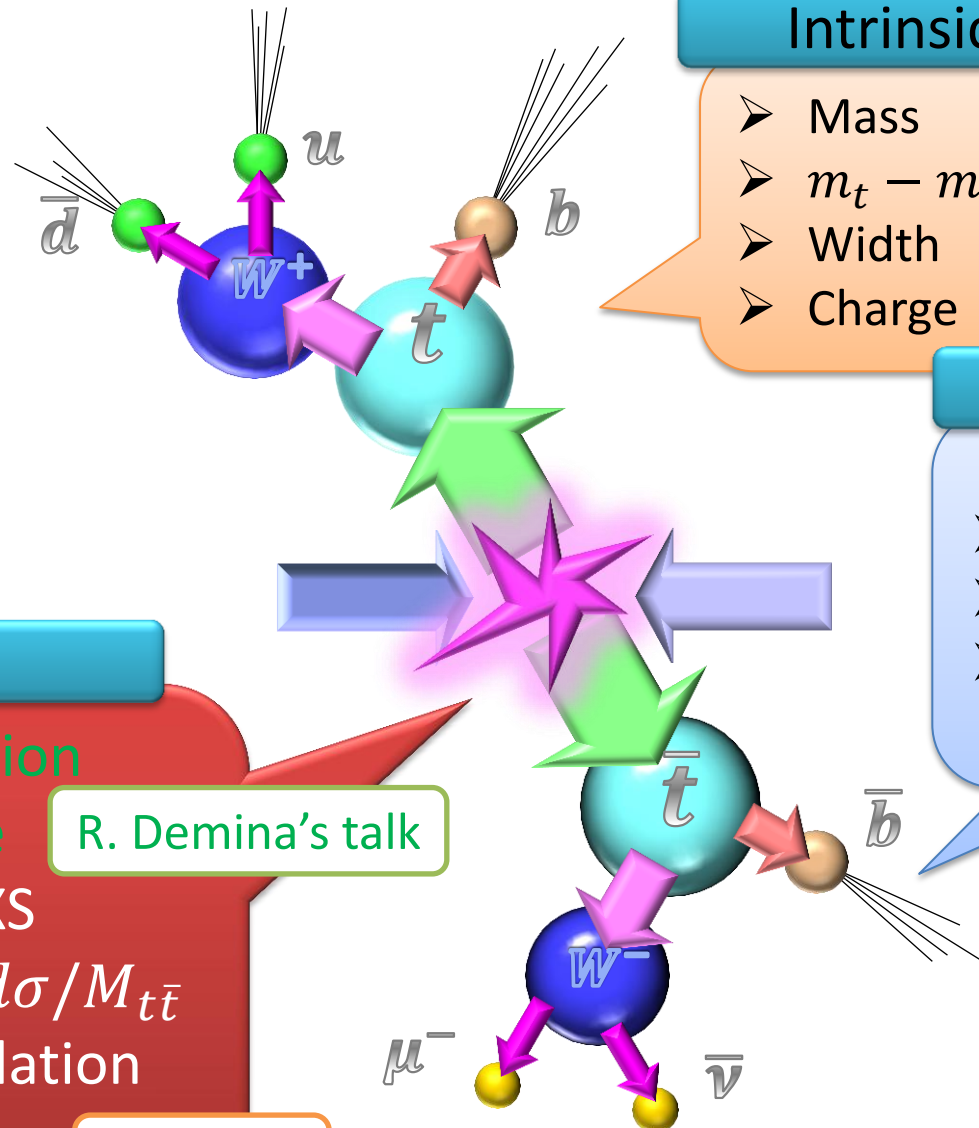
Hadron Collider Physics Symposium 2012

Nov. 13th, 2012

Kyoto University, Kyoto, Japan

Yuji Takeuchi (University of Tsukuba)

on behalf of the CDF and DØ collaborations

Top Quark Properties
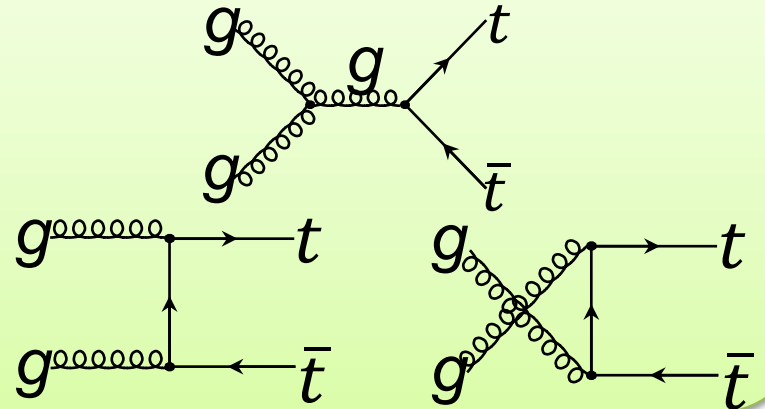
$t\bar{t}$ Production at Tevatron

$q\bar{q}$ annihilation
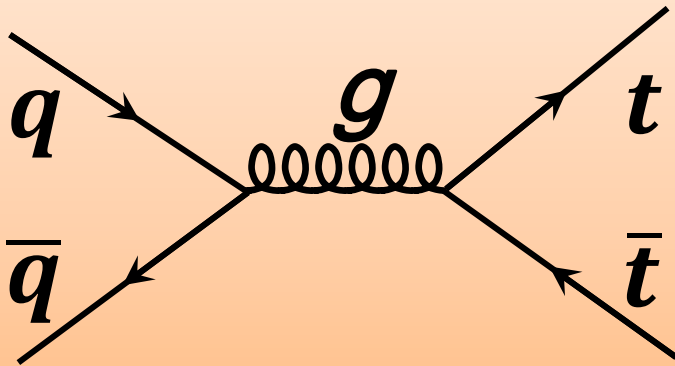
gluon fusion
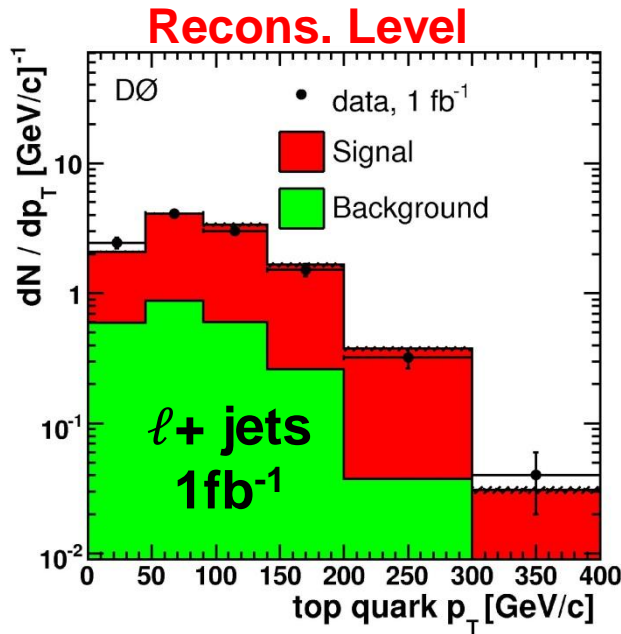

Dominant process at Tevatron

10~20% contribution at Tevatron
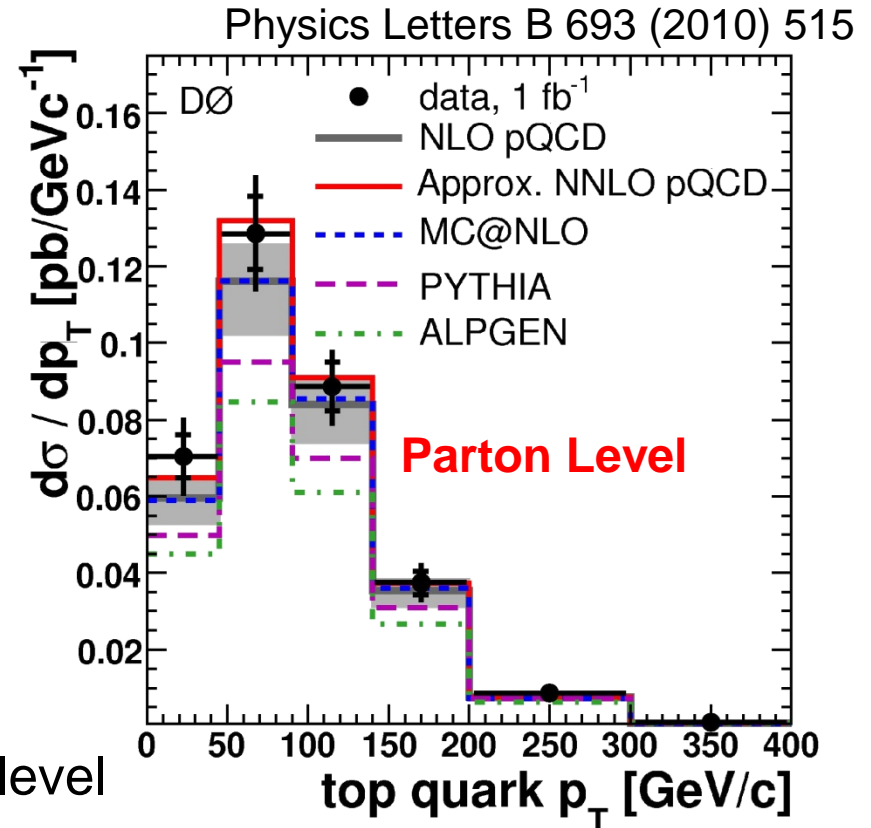Dominant process at LHC

Tevatron is suitable to the study of $q\bar{q}$ annihilation process in $t\bar{t}$ production.

- Also interested in kinematical distributions, differential XS other than inclusive XS.

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$t\bar{t}$ Differential XS ($d\sigma/dp_T^t$)

Recons. Level

ℓ+ jets
1fb^{-1}

data, 1 fb^{-1}
Signal
Background

Physics Letters B 693 (2010) 515

data, 1 fb^{-1}
NLO pQCD
Approx. NNLO pQCD
MC@NLO
PYTHIA
ALPGEN

Parton Level

Unfolding

- ℓ + $\geq$4 jets channel (286 cand.)
- $t\bar{t}$ recons. by kinematical fitting
- Unfolding method to correct to parton level

$$\left(N_i^{\mathrm{Parton}}\right) = A^{-1}S^{-1}(N_j^{\mathrm{Rec}} - N_j^{\mathrm{Bkg}})$$
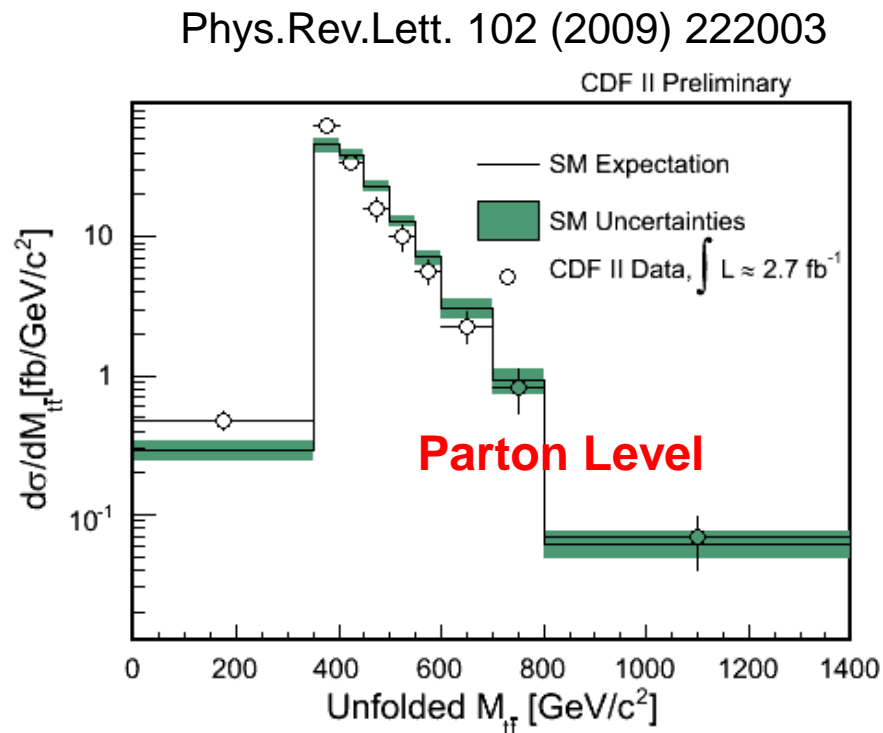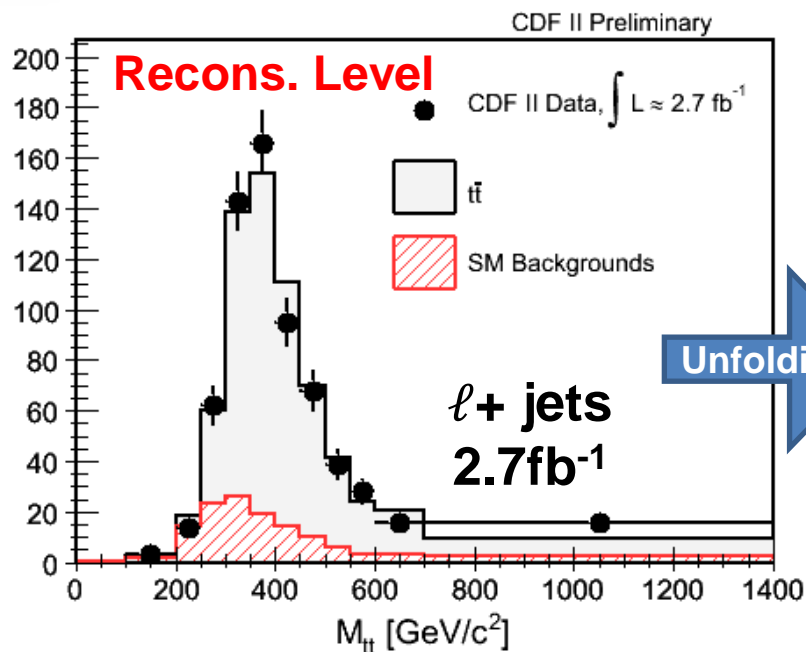
A_i: Acceptance for i-th bin
S_{ij}: Response from i-th bin to j-th recons. bin

Good agreement w/ NLO,NNLO

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$t\bar{t}$ Differential XS ($d\sigma/dM_{t\bar{t}}$)

Recons. Level

CDF II Preliminary

CDF II Data, $\int L \approx 2.7$ fb^{-1}

$t\bar{t}$

SM Backgrounds

ℓ+ jets
2.7fb^{-1}

Unfolding

Phys.Rev.Lett. 102 (2009) 222003

CDF II Preliminary

SM Expectation

SM Uncertainties

CDF II Data, $\int L \approx 2.7$ fb^{-1}

Parton Level

- ℓ + $\geq$4 jets channel (650 cand.)
- $t\bar{t}$ recons. by kinematical fitting
- Unfolding method

No evidence beyond the SM
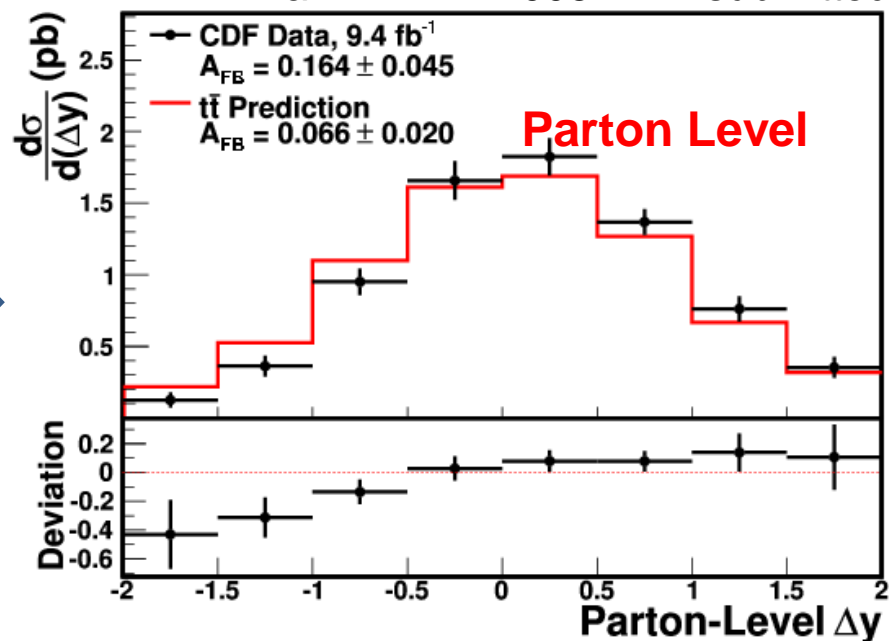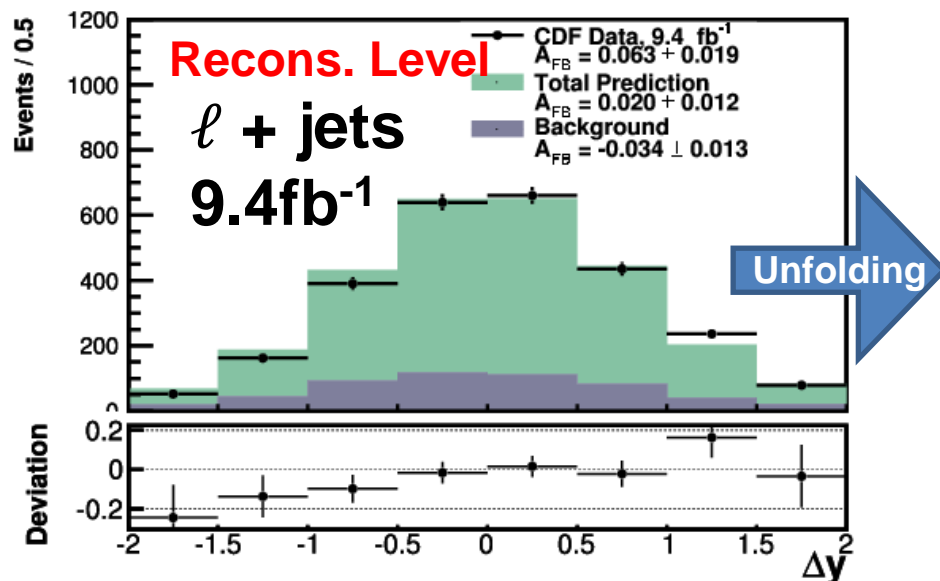$\kappa/M_{\mathrm{Pl}} > 0.16$ (95% CL) for $G \to t\bar{t}$ ($m_1 = 600\mathrm{GeV}$) in RS model
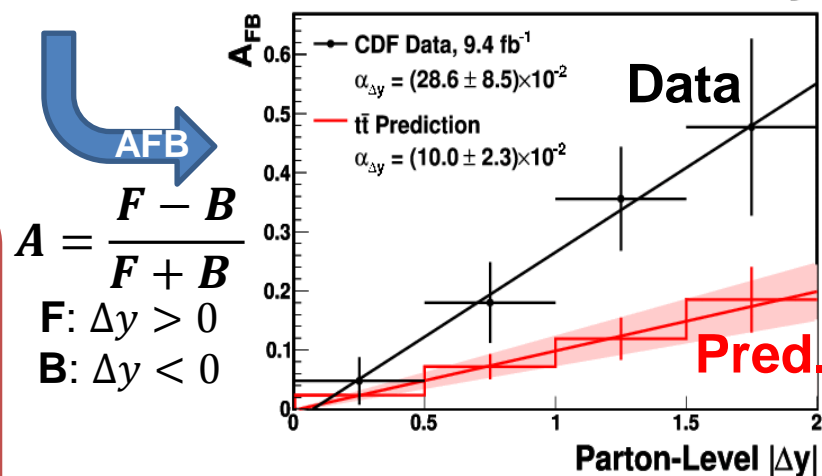
$t\bar{t}$ F-B Asymmetry ($d\sigma/d\Delta y$)

$$\Delta y = y_t - y_{\bar{t}}$$

Recons. Level
ℓ **+ jets**
9.4fb^{-1}

Unfolding

Parton Level

- ℓ + $\geq$4 jets channel (2653 cand.)
- $t\bar{t}$ recons. by kinematical fitting
- Unfolding method

AFB

$A = \dfrac{F - B}{F + B}$

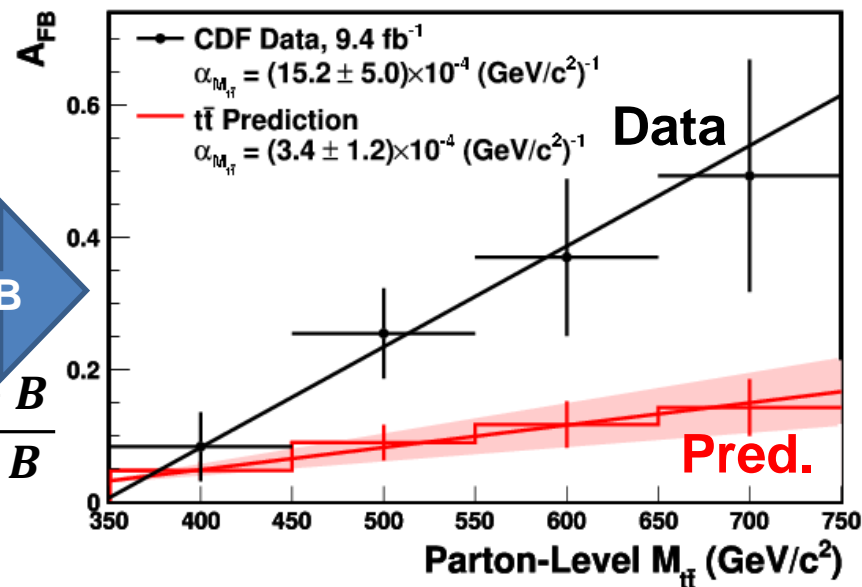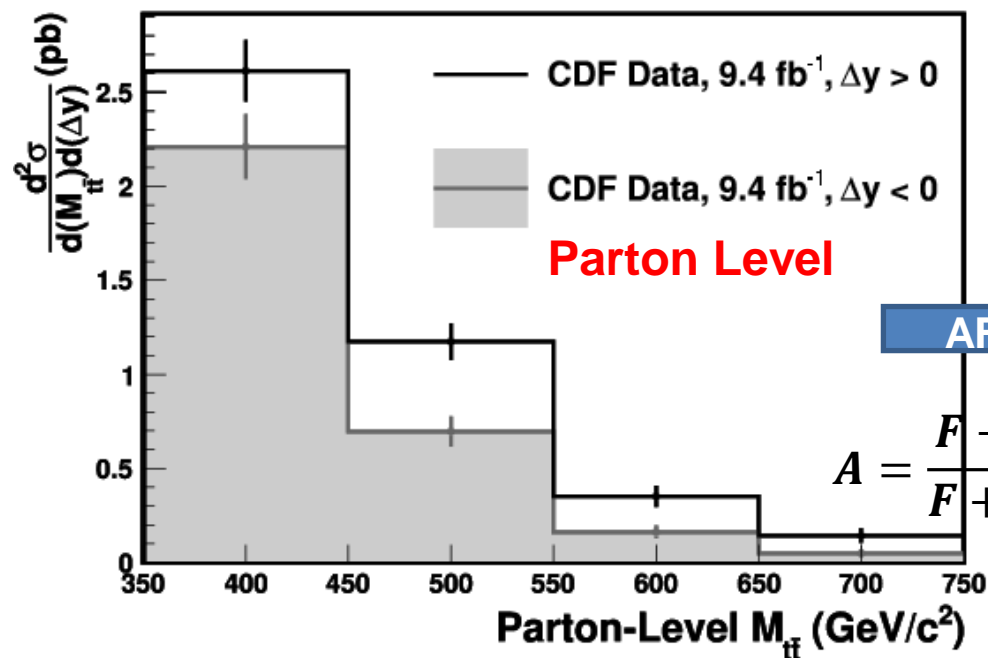**F**: $\Delta y > 0$
B: $\Delta y < 0$

Data

Pred.

- $A = 0.164 \pm 0.039 \pm 0.023$
  2.0σ away from NLO
- $A(\Delta y)$ has linear dep. on Δy
  Slope is larger than NLO pred. (2.2σ away)

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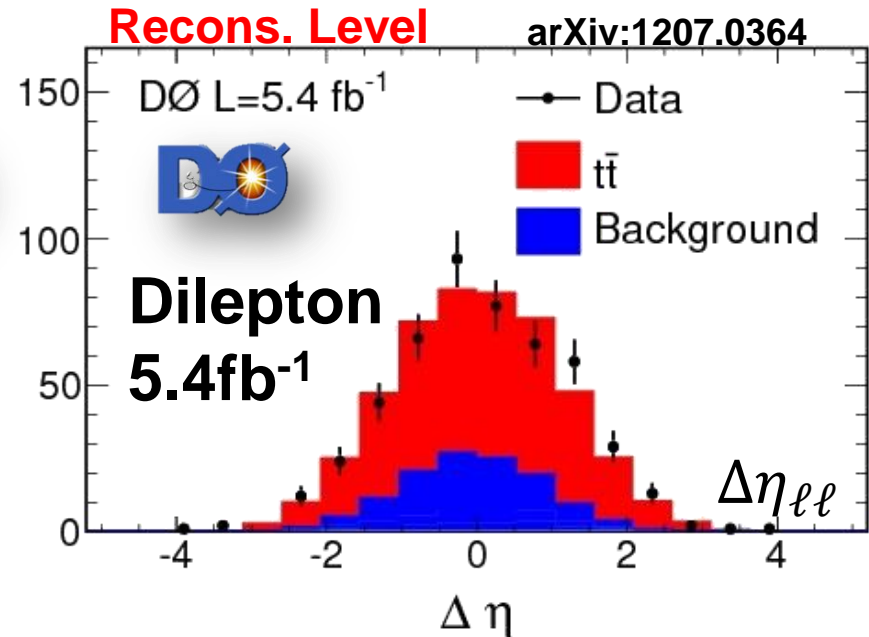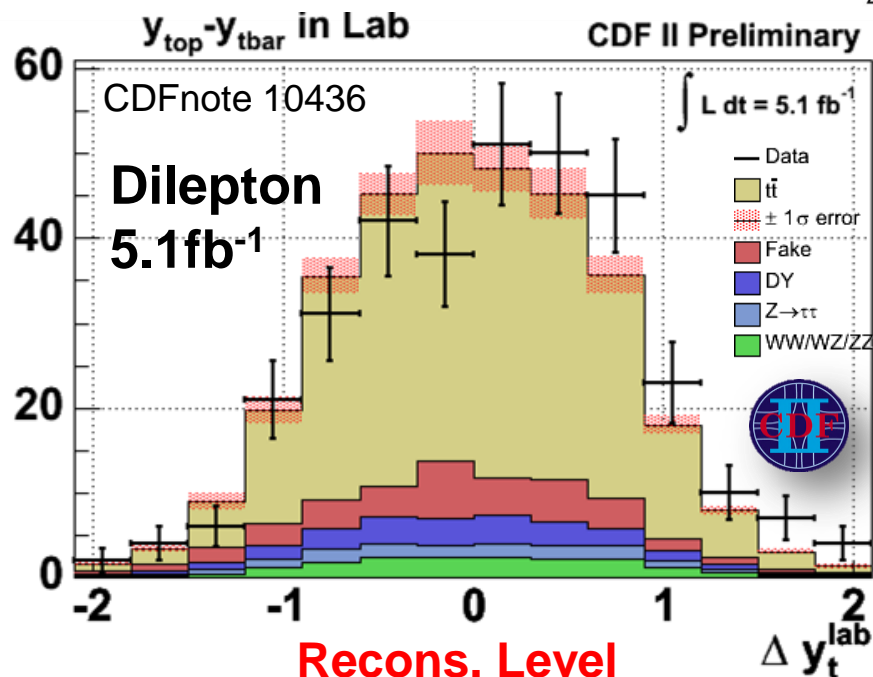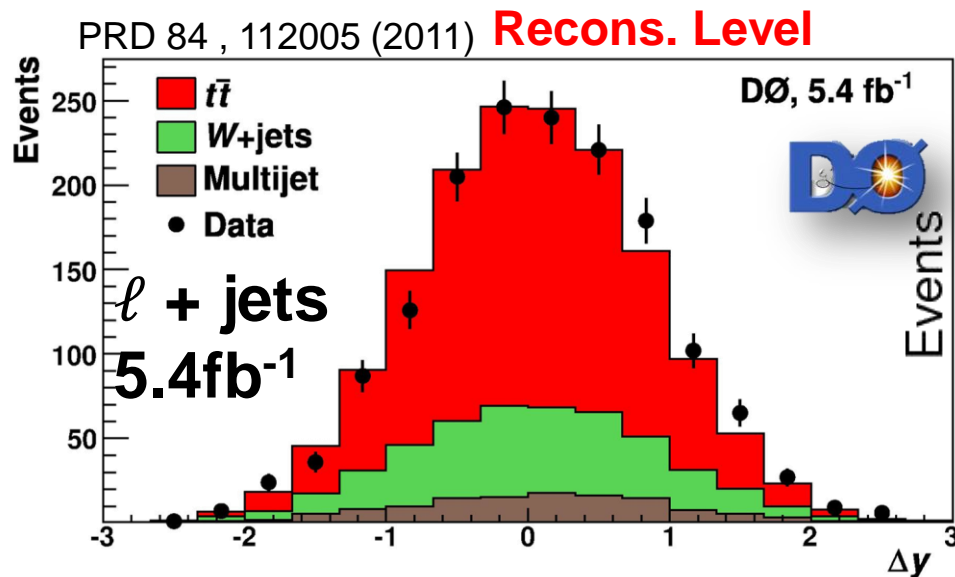# $t\bar{t}$ F-B Asymmetry ($d^2\sigma/d\Delta y \cdot dM_{t\bar{t}}$)

$$A = \frac{F - B}{F + B}$$

- $A(M_{t\bar{t}})$ has linear dependency on $M_{t\bar{t}}$
  Slope is larger than NLO pred. (2.4σ away)

Other AFB measurements at Tevatron

Recons. Level

Recons. Level

ℓ **+ jets**
5.4fb^{-1}

D0, 5.4 fb^{-1}

- $t\bar{t}$
- W+jets
- Multijet
- Data

Δy

D0 L=5.4 fb^{-1}

- Data
- $t\bar{t}$
- Background

Dilepton
5.4fb^{-1}

$\Delta \eta_{\ell\ell}$

$\Delta \eta$

$y_{top} - y_{tbar}$ in Lab   CDF II Preliminary

CDFnote 10436

$\int L\, dt = 5.1\ \text{fb}^{-1}$

Dilepton
5.1fb^{-1}

- Data
- $t\bar{t}$
- $\pm 1\sigma$ error
- Fake
- DY
- $Z \to \tau\tau$
- WW/WZ/ZZ

Δy_t^{lab}

Recons. Level

- Δy dist. in D0 ℓ+jets and CDF dilepton also indicate larger asymmetry than expected (2~3σ)
- Lepton asymmetry ($\Delta\eta_{\ell\ell}$) in D0 dilepton is consistent with pred.

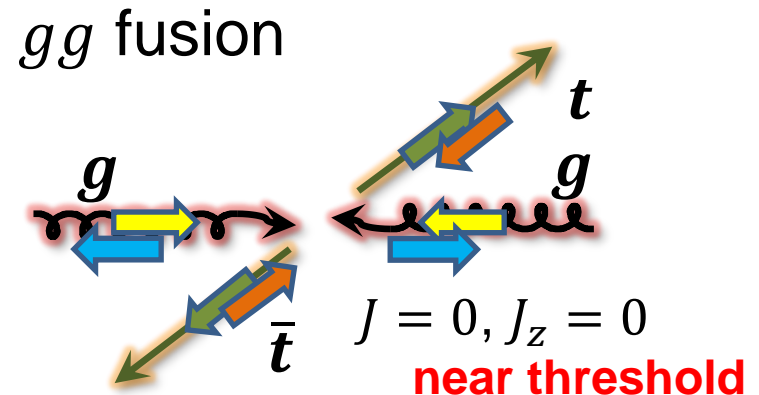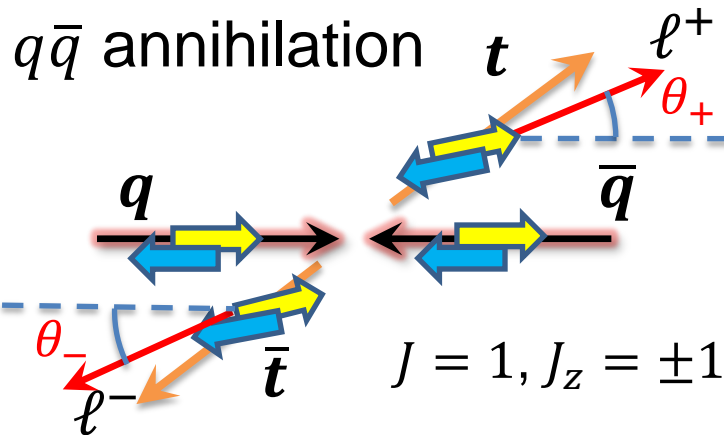More detail will be given in R. Demina's talk in plenary session tomorrow

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Top Polarization and Correlations at $t\bar{t}$ production

Because top quark decays before losing polarization, $t/\bar{t}$ polarization and their correlations can be measured as angular distribution of decay products from $t\bar{t}$.

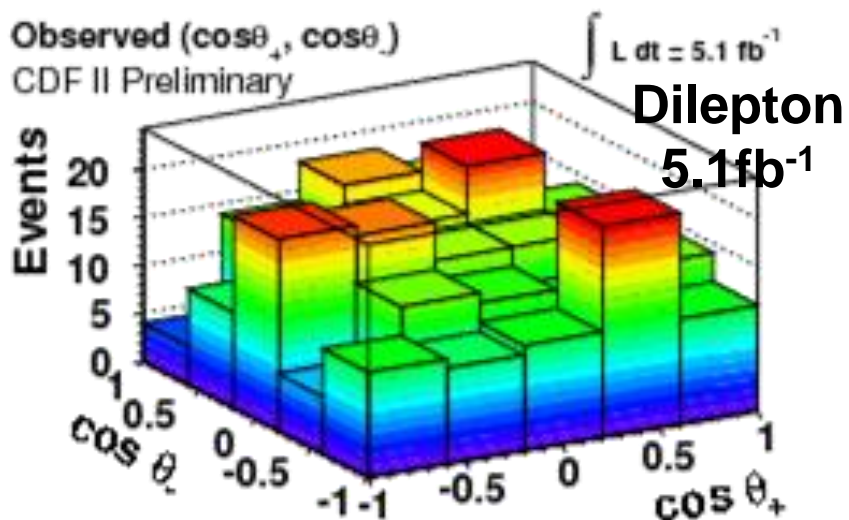$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = 1 + C\cos\theta_+\cos\theta_-$$

$q\bar{q}$ annihilation

$J = 1, J_z = \pm 1$

gg fusion

$J = 0, J_z = 0$

near threshold

More sensitive to $t\bar{t}$ production mechanism than other kinematic variables.
➔ Might give a hint on $t\bar{t}$ F-B asymmetry.
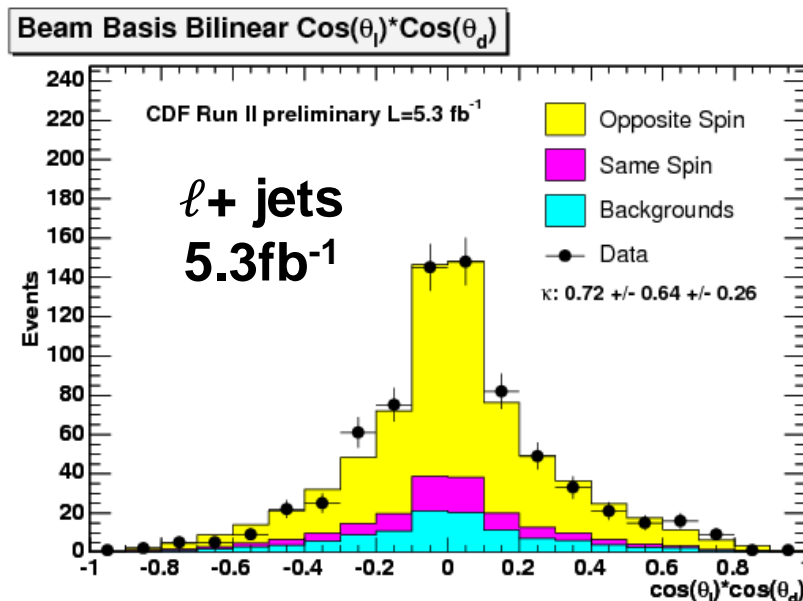
Spin Correlation at CDF

- Dilepton channel (334 cand.)
- Extract C_{beam} from reconstructed 2D $(\cos\theta_+, \cos\theta_-)$ distribution

- $\ell + {\geq}4$ jets channel (725 cand.)
- up/down quark identification
  up-type is more energetic
- Extract C_{beam} from $\cos\theta_+ \times \cos\theta_-$

Dilepton 5.1fb⁻¹

ℓ+ jets 5.3fb⁻¹

$$C_{beam} = 0.04 \pm 0.56$$
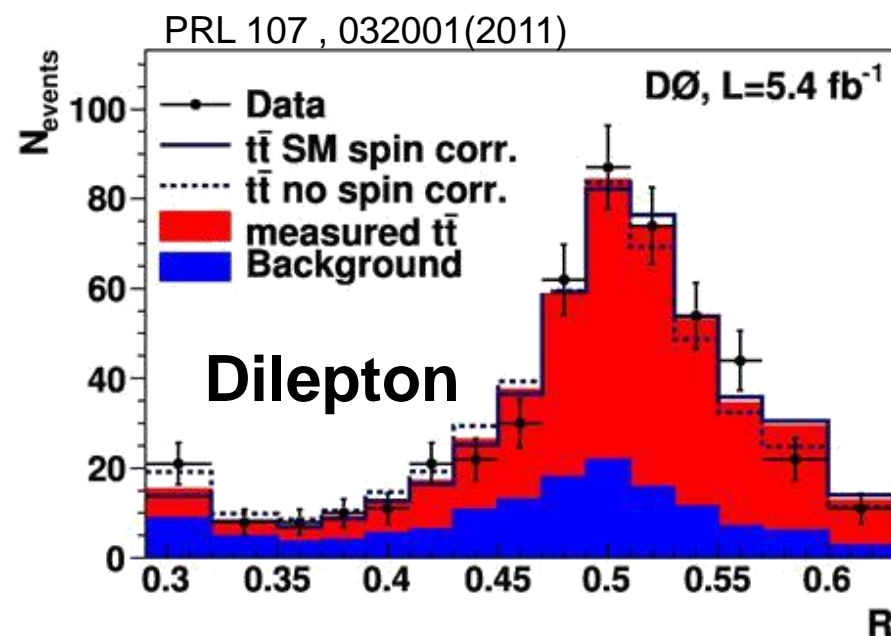
CDFnote 10719

$$C_{beam} = 0.72 \pm 0.64 \pm 0.26$$

CDFnote 10211

($\Leftrightarrow$SM pred.: $C_{beam} \sim 0.78$)

Consistent with SM, but statistically limited…

Spin Correlation at DØ

- Dilepton (485 cand.) $\oplus$ ℓ + $\geq$4 jets (729 cand.)
- Matrix element method
  - Event probabilities on SM-correlation ME (P_c) and No-correlation ME (P_u)
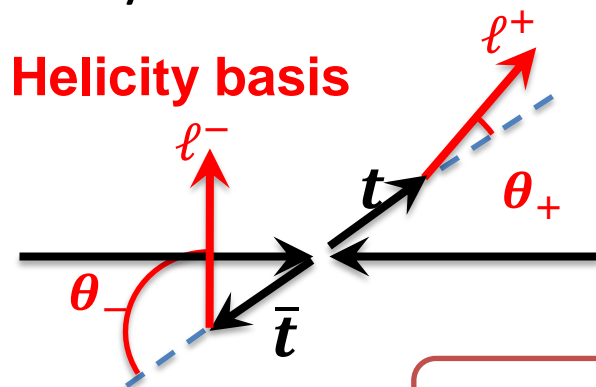 - Discriminant R=Pc/(Pc+Pu)
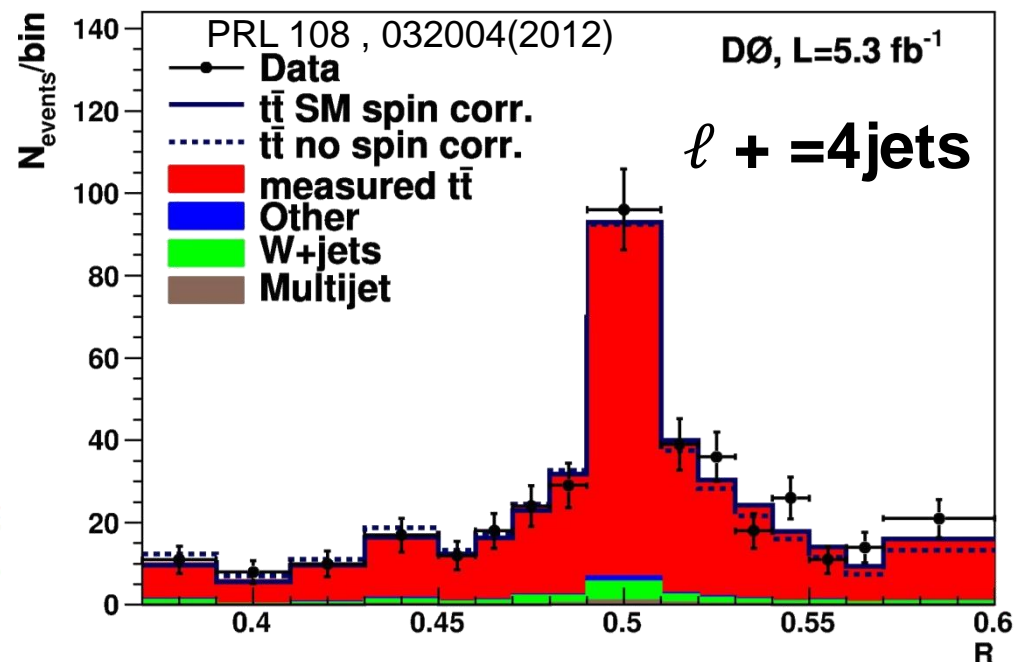
Measured fraction of SM correlation $f^{SM} = 0.85 \pm 0.29$
(f=1: SM, f=0: no correation)

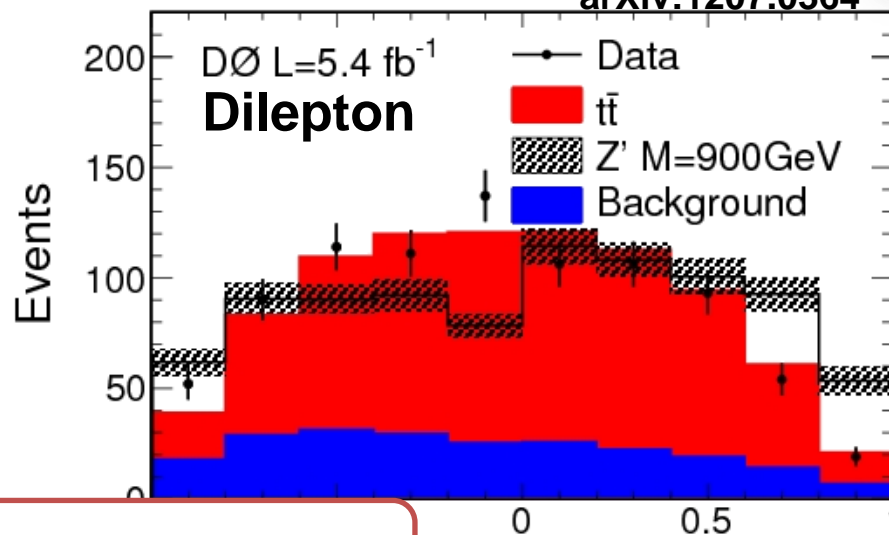**Exclude the no-correlation hypo. at 99.84% CL (3.1σ)**

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Top polarization in $t\bar{t}$ production

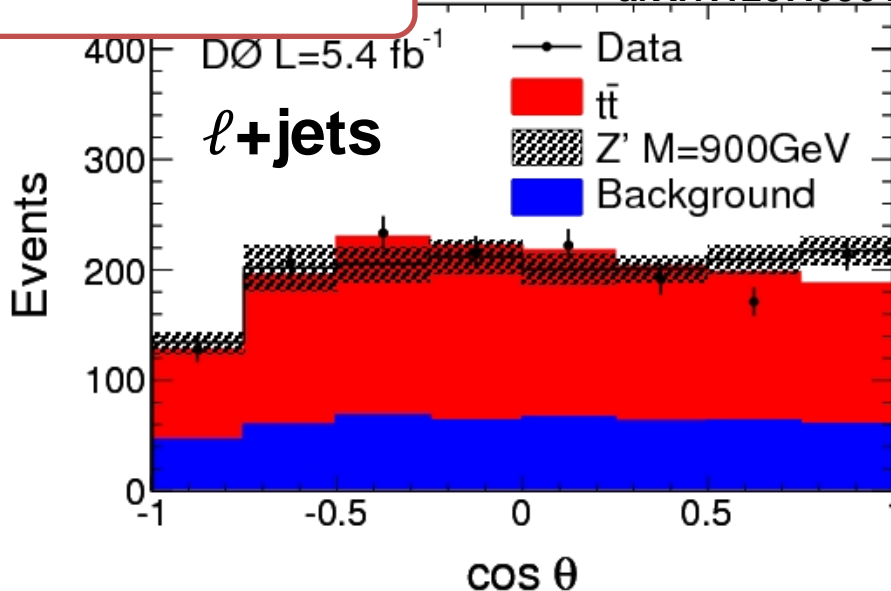Top polarization along to helicity axis

Helicity basis

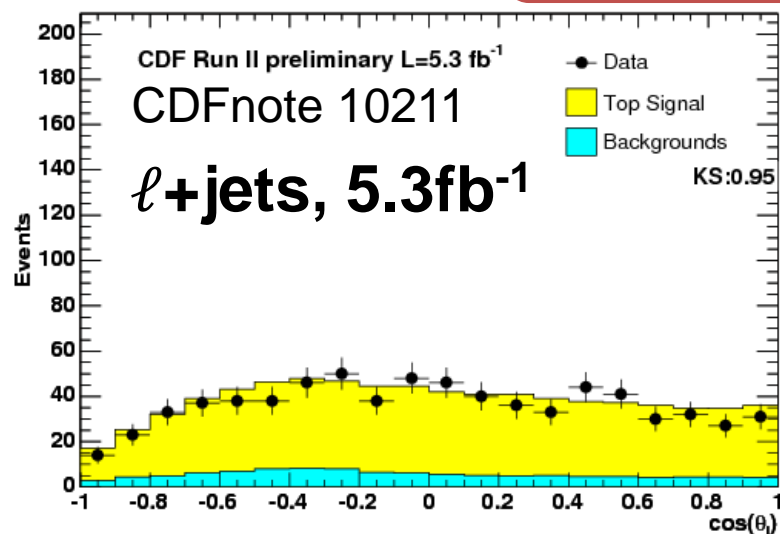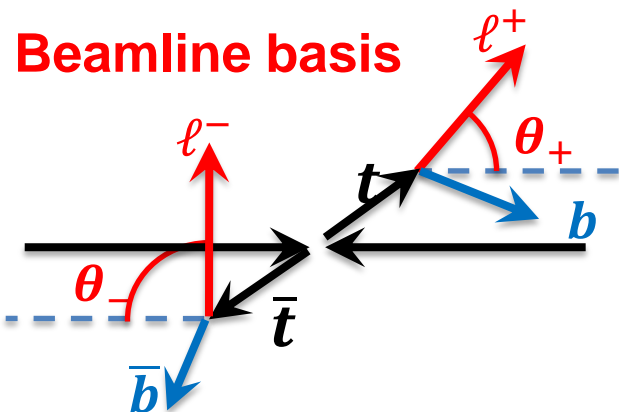
No evidence beyond the SM

arXiv:1207.0364

DØ L=5.4 fb^{-1}
Dilepton
Data
$t\bar{t}$
Z' M=900GeV
Background

arXiv:1207.0364

Cosine of Lepton Helicity Angle

CDF Run II preliminary L=5.3 fb^{-1}
CDFnote 10211
ℓ+jets, 5.3fb^{-1}
Data
Top Signal
Backgrounds
KS:0.95
$\cos(\theta_l)$

DØ L=5.4 fb^{-1}
ℓ+jets
Data
$t\bar{t}$
Z' M=900GeV
Background
$\cos\theta$
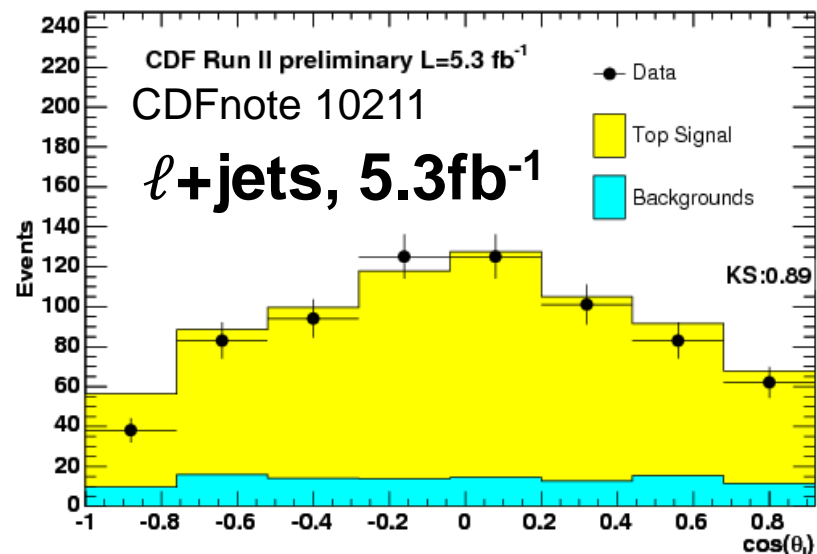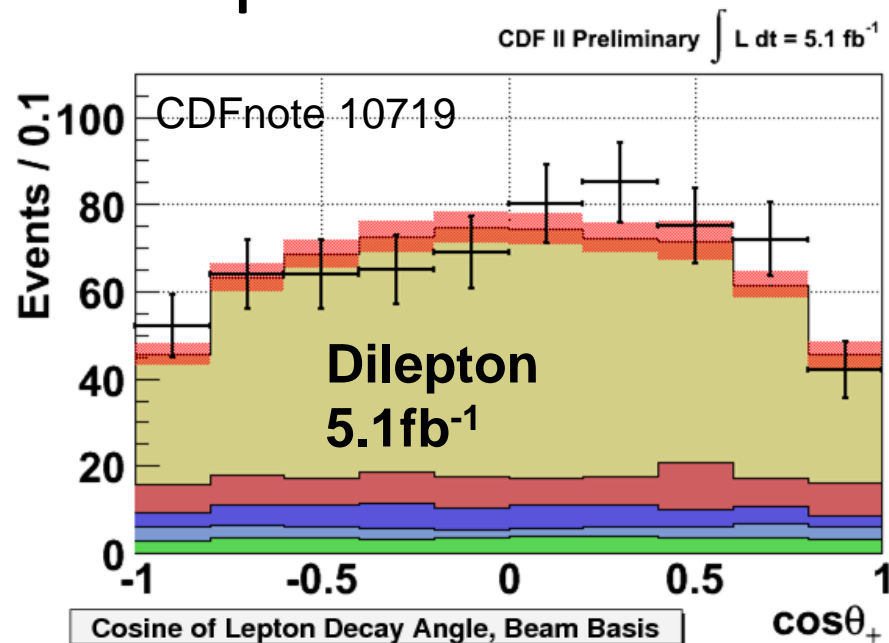
Top polarization in $t\bar{t}$ production

Top polarization along to beamline axis

Beamline basis

No evidence beyond the SM

CDF II Preliminary $\int L\,dt = 5.1\text{ fb}^{-1}$

CDFnote 10719

Dilepton 5.1fb^{-1}

Cosine of Lepton Decay Angle, Beam Basis

$\cos\theta_{\pm}$

CDF Run II preliminary L=5.3 fb^{-1}

CDFnote 10211

ℓ**+jets, 5.3fb^{-1}**

KS:0.89

- Data
- Top Signal
- Backgrounds

$\cos(\theta_l)$

Summary

- Tevatron gives unique opportunity to study $q\bar{q} \rightarrow t\bar{t}$ production process for detail.
  - Kinematical distributions of $t\bar{t}$, $d\sigma/dX$ imply more information.
- $t\bar{t}$ AFB measurements at Tevatron suggest a contribution from new physics.
- Thanks to top quark short life-time, we can probe top quark polarization at $t\bar{t}$ production as well.
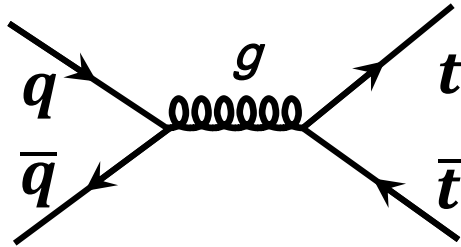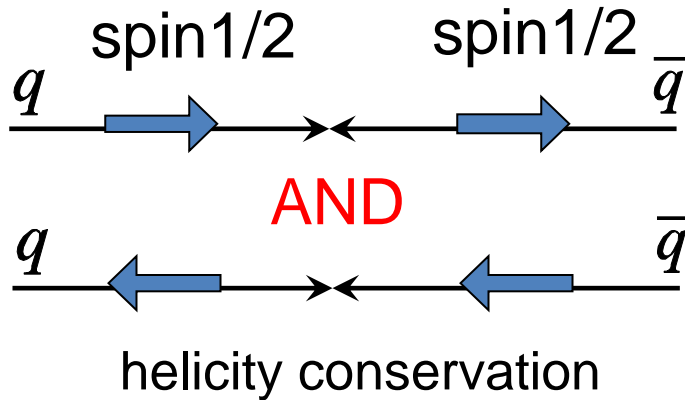 - This might give more information on AFB.

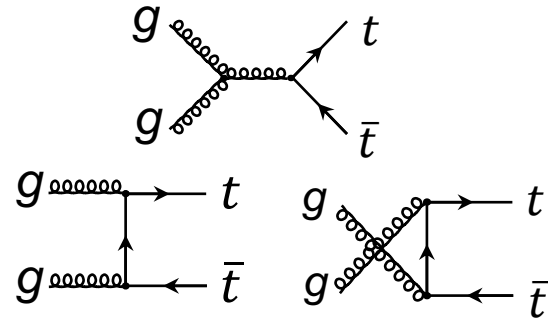# Backup

Reconstructed $p_T(t\bar{t})$
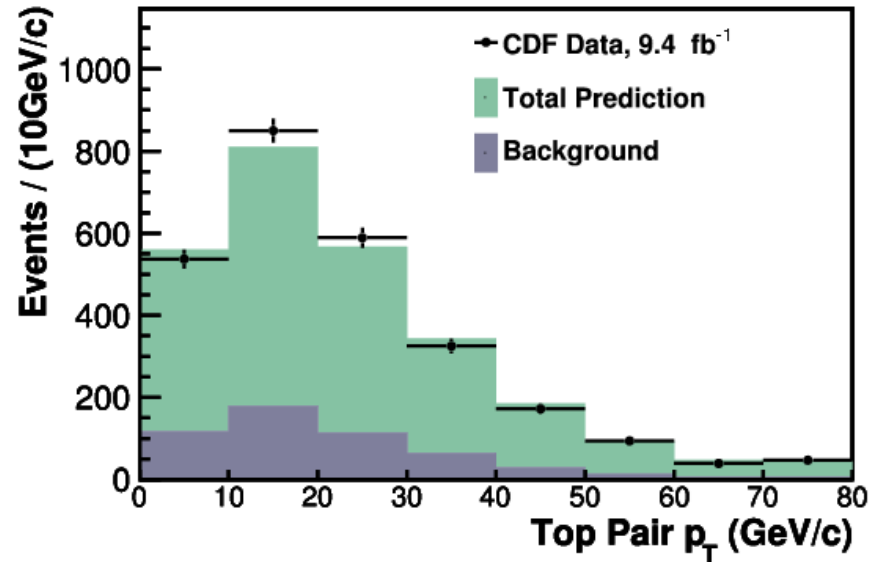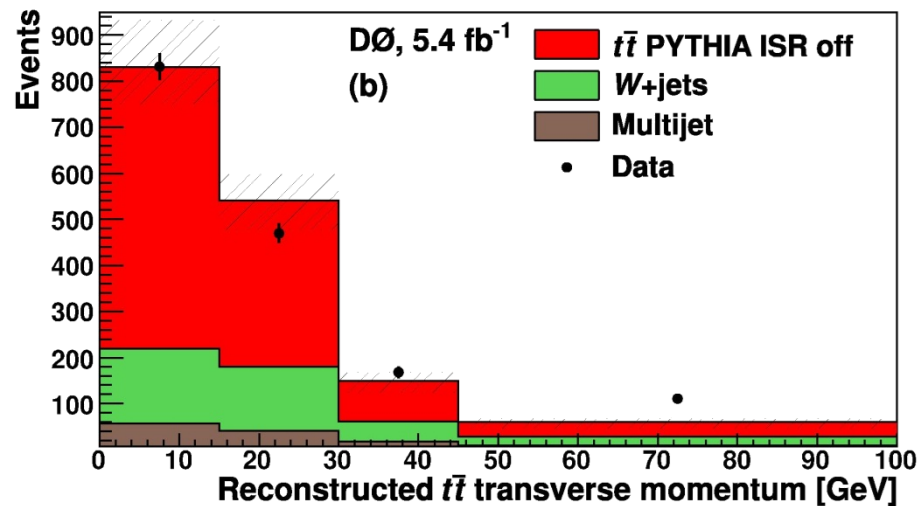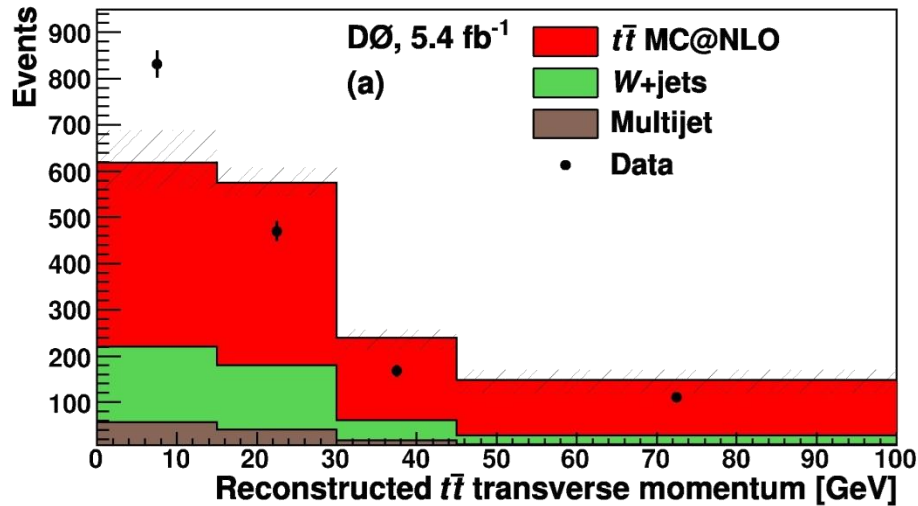
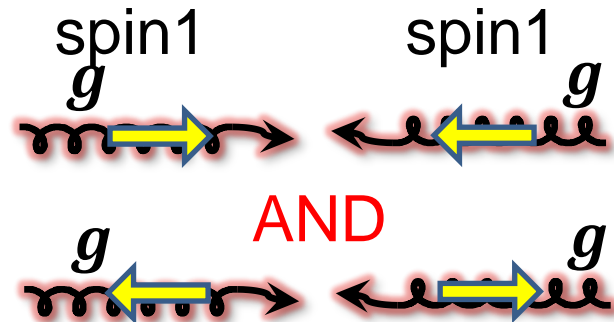# Top/anti-top polarizations at $t\bar{t}$ production

Dominant process at Tevatron

spin1/2   spin1/2 $\bar{q}$

AND

helicity conservation

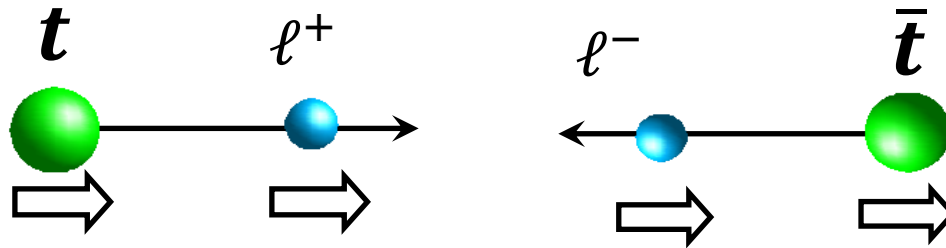J=1, Jz=±1

At $t\bar{t}$ threshold

spin1   spin1

AND

J=0, Jz=0
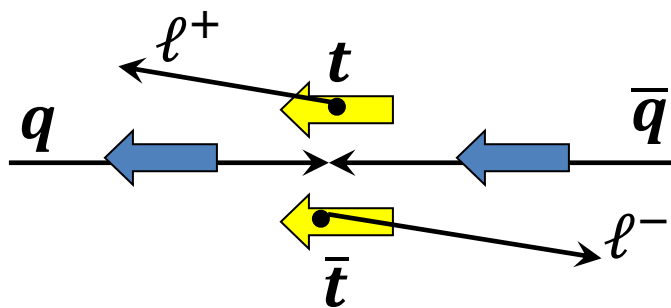
$t\bar{t}$ has correlations in their polarizations

— in different way for $q\bar{q}$ and gg processes —
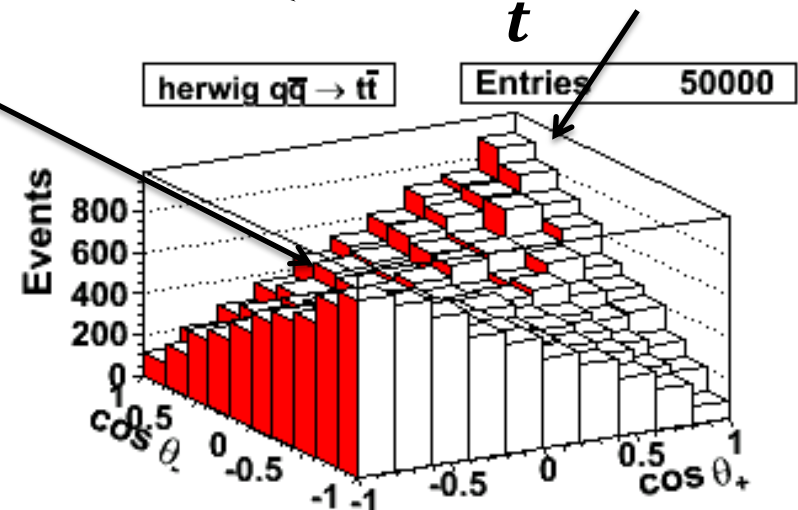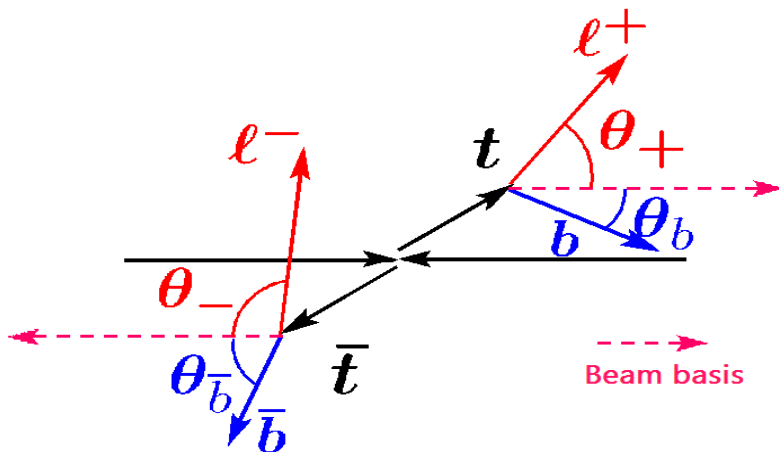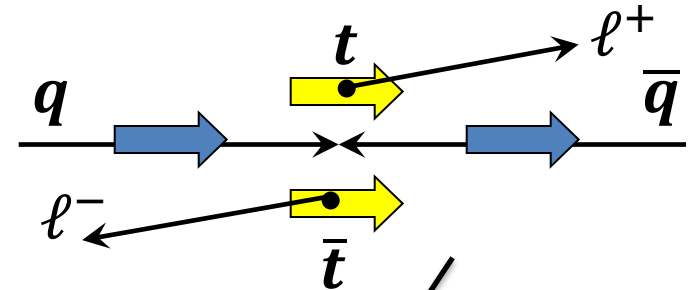
Spin Correlation in $q\bar{q} \to t\bar{t}$ process

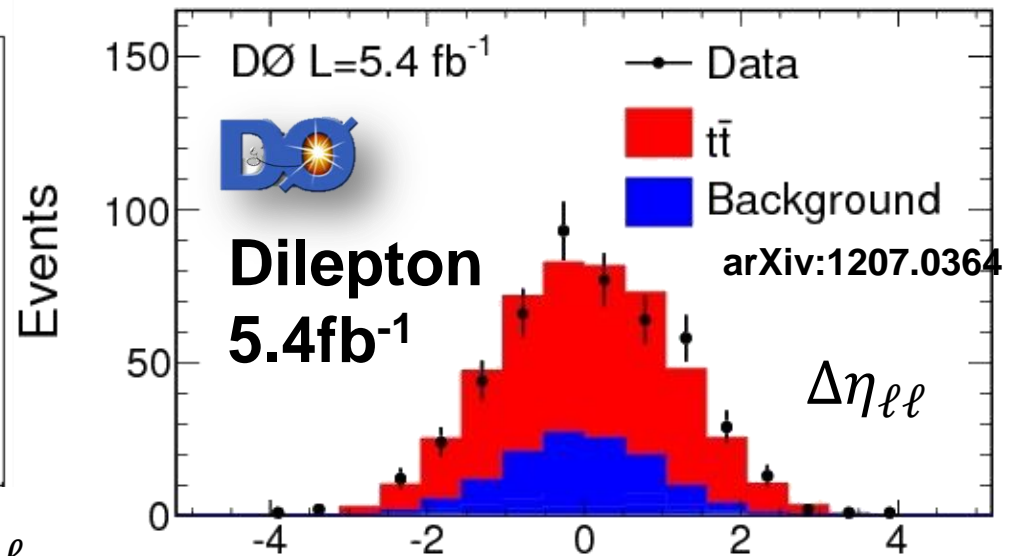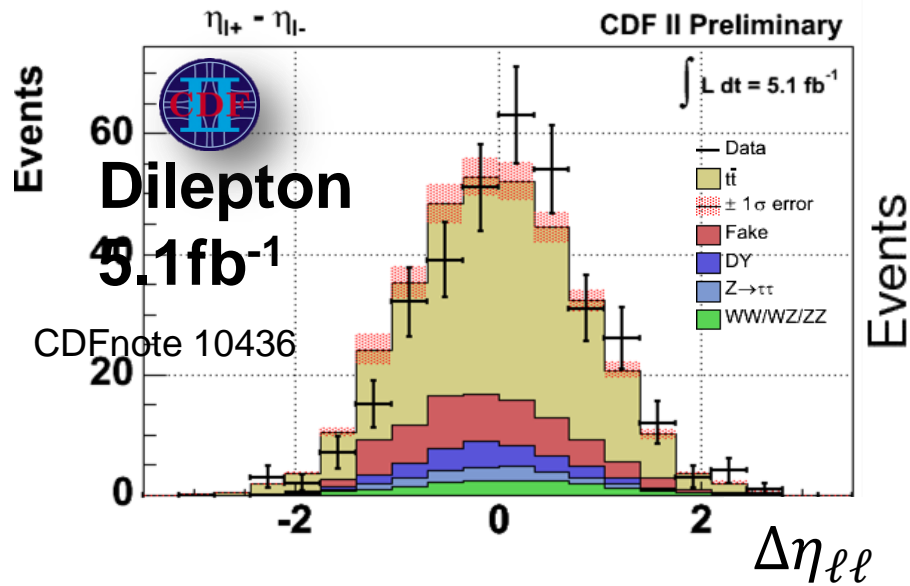Top quark polarizations can be probed via lepton flight direction

$q\bar{q} \to t\bar{t}$ (near threshold)

AND

$q\bar{q} \to t\bar{t}$ Herwig MC at parton level

Lepton asymmetry in $t\bar{t}$ events at Tevatron

Dilepton 5.1fb^{-1}

CDFnote 10436

$\Delta\eta_{\ell\ell}$

Dilepton 5.4fb^{-1}

arXiv:1207.0364

$\Delta\eta_{\ell\ell}$

- ## CDF dilepton
  - $A^{\mathrm{raw}}(\Delta\eta) = 0.14 \pm 0.05$
- ## D0 dilepton
  - $A^{\mathrm{raw}}(\Delta\eta) = 0.03 \pm 0.06$
- ## D0 l+jets
  - $A^{\mathrm{raw}}(q \cdot \eta) = 0.14 \pm 0.04$

$q \cdot \eta_\ell$

ℓ+ **jets 5.4fb^{-1}**

PRD 84 , 112005 (2011)